Adaptation and improvement of ASW Tactical Decision Aid Design to Mine Warfare Tactical Decision Aid

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***Abstract*-In this presentation, the adaptation of a tactical decision aid (TDA) designed for Anti Submarine Warfare (ASW) to one used for Mine Warfare is discussed. Previous work at the Naval Research Laboratory established a TDA, namely GRASP for the ASW role. Recently at NRL work has been done to extend the TDA model to Mine Warfare. Specifically this presentation examines search path algorithms for the two TDAs. Comparisons will be shown between various search path algorithms for environmentally influenced mine detection: GRASP, edge covering, and greedy algorithms for limited time searches and searches for assured threshold confidence of detection. Oceanic environmental parameters relevant to designing tactical decision aids for mine detection will be noted. In conclusion this presentation discusses how extensively detailed must the environmental survey be in order to make search path analysis sensitive to the data.**

I.INTRODUCTION

In mine warfare measures of effectiveness and performance are defined in which a searcher's effectiveness is determined by the percent of mines cleared. Environmental effects are not taken into account by the current measures of effectiveness. Historically there are good reasons for this 1) not enough environmental data. 2) before the computer revolution operational decision aids needed to be tabular with very few variables 3) under isotropic environmental conditions this was equivalent to the desired behavior. In resent years there have been considerable advances in both the quantity and quality of environmental data as well as increased acceptance of algorithm-derived operational aids.

Another good reason for not having a worked solution is that in the general case, the problem is equivalent to the traveling salesman problem, an NP hard problem [1]. NP hard problems are those whose solution times are not known to be asymptoticly bounded by any polynomial formula of the number of points, N, considered as N increases. Practically this implies that over a certain rather low threshold for N brute force calculations become ineffective. It is unlikely that such a formula will be found for these problems. Finding such a formulation or proving that no such formulation exists is one of the top ten mathematical problems of the century as noted in [1] We will leave such work to others.

Practically there are several approximate solutions for this problem. We will look at some of them including Monte Carlo, greedy, ladder and edge covering. We show some development on a greedy algorithm.

II. ENNVIRONMENTAL EFFECTS

First let us justify that there is a problem. As of now the standard procedure in Mine Counter Measures (MCM) is to consult the Uniform Coverage Planning (UCPLN) program. It requires from the user the effectiveness of the MCM technique being used and the desired percent clearance. The program outputs the number of tracks , the fixed distance between the tracks, and the number of times each track should be repeated.

However, oceanographic environmental variability can be large enough across a given region for some of these fixed values to become variables. For example, sound speed profiles are influenced by internal waves in the environment. These changes in sound speed can influence the area above a detection threshold. Fig. 1 shows the are of signal excess calculated using a parabolic equation solver[2] for the case without an internal wave. Fig. 2 is the same case with an internal wave. As can be seen the range of detection at the surface has increased by approximately a factor of three. These figures point to two errors that can be induced by not including the environmental data. First in the case the internal wave is ignored, the assets searching spend three times the necessary time to search a given volume. Second if the internal wave situation in guessed incorrectly, then the search will not be thorough enough.

As the TDA becomes more sophisticated environmental variability might suggest tracks other than straight paths. Variability of mine sweeping platforms would also change current UCPLN programs. Current programs integrate the movement limitations inherent in current mine sweeping platforms and equipment. Namely towed equipment works best towed in a straight line. As the Navy is transformed this limitation will not always be present for example in autonomous underwater vehicles (AUVs).

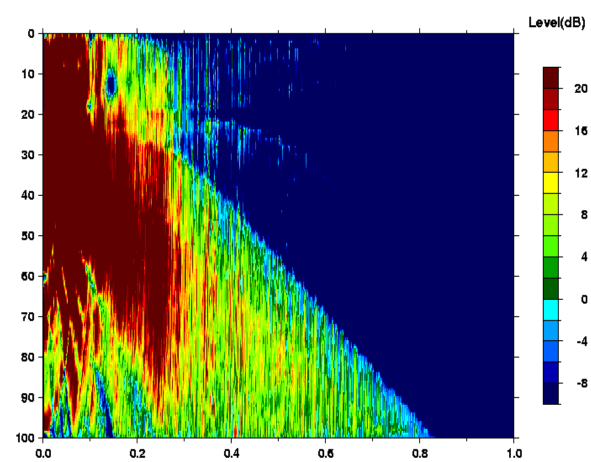

Figure 1. Signal Excess in dB for the no internal wave case. Depth on the y axis and range on the x axis. Black to the right is below the threshold.

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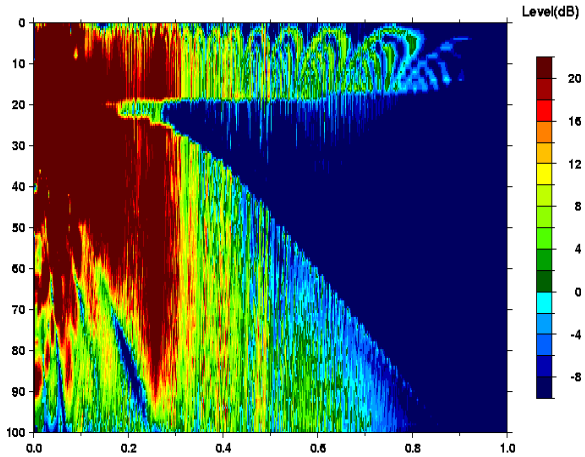

Figure 2. Signal Excess in dB for the internal wave case. Same parameters as fig. 1.

Searches for mines on the bottom are generally short ranges so propagation rarely noticeable in effect. However propagation will have an effect when searching at long ranges for mines suspended in the water column and near the surface. This implies that sound speed profiles can occasionally be a determining factor.

Ocean currents will determine where a floating mine drifts and will in some circumstances automatically clear an area, rule out an area or give a spread form a known deployment point.

Wind direction/ wave direction also needs to be considered from an operational aspect. Ie. wallowing in the waves to be avoided if possible.

A. Isotropic Environments

Isaacs in [3] delves into the Isotropic problem under the topic of search games with immobile hiders. There are a few differences between the assumptions of his search game and searches involved in MCM. Notably that drifting mines are mobile, however the speed of drift is low compared to speed of the searcher and the movement is not directed to avoid detection. Therefore the immobility assumption still holds. Another assumption is that the search platform can keep a constant speed and turn freely. This is generally not true for MCM in that streaming gear will take a performance hit during a turn and the platform general turns at lower speed , but is approximately correct. Isaacs states that any search pattern that does not overlap is maximal in the isotropic case. Any overlap creates duplication, so any path that covers and has no duplication will be maximal. The traditional MCM procedure assumes an isotropic environment so a ladder pattern is wisely chosen to be the default pattern for searching. As a corollary when using multiple searchers, each searcher should be give a separate equal area to examine. The new search time will be *T*, the search time for one searcher, divided by *n*, the number of searchers assuming all searchers are equal.

B. Piecewise Isotropic Environments

Similarly piecewise isotropic environments can be treated as separate isotropic problems if the boundary length multiplied by the sweep length at the boundary is small compared to the search area. These can be solved by moving with the appropriate ladder pattern for each environmental area taking care to travel boundary regions on the more visible side.

If the search is time dependent such that the search time allotted is shorter than that needed to completely scan the search area, the problem becomes less obvious. At first examination the searcher would travel to the most visible area first. However if the travel time from the start to the most visible area is long, then this would not be maximal. Also at this point one has to consider what the mine placer would do in this situation. It is more likely that the mines will be hidden in the less visible areas than in th more visible ones. For the time limited case the ladder search can be less than maximal.

C. Sweep Scale Distributed Environments

The piecewise isotropic environment approximation best fits the current state of most oceanographic databases that province the ocean in terms of minutes [4. The highest resolution database available is the Ocean Floor Depth Digital Bathymetric Data Base Variable Resolution (DBDB-V) with a resolution of .1 minute where the resolution is available. Low Frequency Bottom Loss, High Frequency Bottom Loss, Shipping Noise, Signal to Noise Databases all have a resolution of 5 minutes. Sound speed profiles are provinced seasonally at between 12 and 30 minutes. The resolution is coarse enough that each province can be treated separately.

However it is well known that the actual oceanographic environment can have acoustically noticeable fluctuations down to the sub-meter scale [5]. The experiment sited found that for an area off the New Jersey coast, bottom sound speed at varied by 100 m/s and antenuation varied by 25 dB/m on kilometer scales for a 65kHz signal. Sub-meter measurements found hot spots of 25 dB/m attenuation and 50 m/s in sound speed variability. Another example within this category is that of the bubble clouds underlying the sea surface. At wind speeds above 5m/s the sea surface is always accompanied by a patchy layer of micro bubbles forming clouds. Their presence affects all sonar frequencies, and can severely affect the detection of floating mines. At the high frequencies typical of mine hunters sonars they affect mostly the attenuation and to a lesser degree the sound speed, but the clouds also produce false echoes. Their effect can reach depths to about 10-15m and can either mask the presence of floating mines or severely degrade the signal to noise ratio for detection. At a wind speed of 13 m/s the bubble induced attenuation is about 0.2dB/m at 2 m below the surface for a 65kHz signal and .5db/m for a 200kHz signal. At 5m depth they reduce to 0.2 and 0.5 dB/m respectively, which are still substantial. They effects are also highly variable in range. At 2m below the surface hot spots of very hight attenuation 300dB/m and higher occur over distance of 5 or 10 meters [6].

Acoustical environments with variability that does not fit the piecewise isotropic model will be labeled sweep scale

distributed environments. That is the environment varies on the order of the acoustic search instruments maximum range. On such environments a ladder pattern would normally be set to a more conservative sweep size value implying considerable overlap between paths assuring that the path will not be maximal. In this case there is a clear need for a better search algorithm. From the above sited experiment and model, as well as our introduction to acoustical environmental variability, it follows that in many ocean environments the randomly distributed environmental variability case occurs at high frequencies.

III. SEARCH ALGORITHMS

A Modified Ladder Type

As stated previously the fixed ladder search is ideal for media where only the average search range is know. The fixed ladder search is also the maximal search pattern for isotropic environments. These patterns are easy to describe, code and implement. These algorithms also include the modified ladder algorithms that vary the distance between ladder rungs based on the differing search ranges in the different acoustical environmental provinces. Fig. 3 is an example of the modified ladder search.

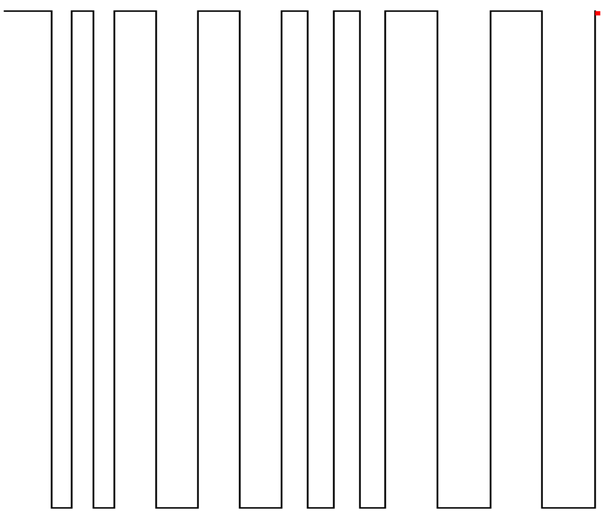

Figure 3. Example of a modified ladder search pattern.

B. Edge Covering

The Edge Covering search algorithm is easy to state but hard to code. An edge covering search warps the rungs of a ladder search to insure coverage to the edge of the rung before without overlap as can be seen in Figure 4. Easy by eye to create such a path for full coverage cases, but a strict coding that will handle random coverage patterns is not a straight forward exercise. Also like greedy algorithms they are not usually compatible with towed MCM devices because of the frequent turning.

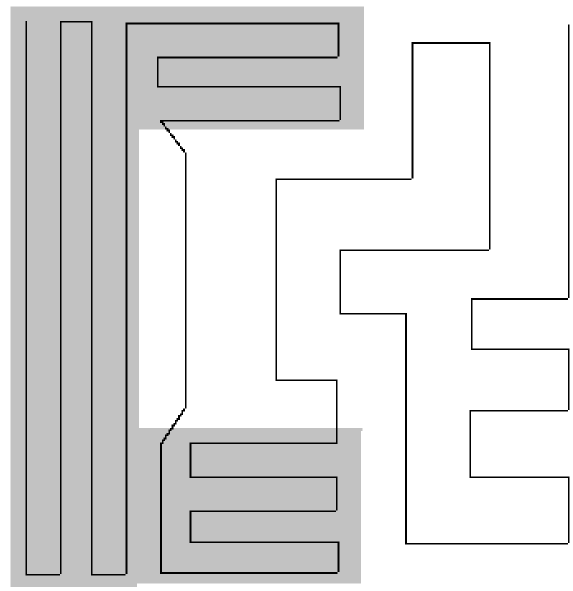

Figure 4. Example of an edge covering search pattern. Gray areas are of lower visibility.

C. Monte Carlo Searches

GRASP [7] was borrowed from its use in the ASW area. Essentially it begins with a set of randomly generated search paths. It then perturbs these paths and uses a coverage fitness function on each path. Then it selects the top few paths, perturbs them and repeats. The process is weakly convergent so run times are usually lengthy. GRASP is principly used for planning time limited searches. Time limited searches are searches lasting much less time than needed to fully search the operational area. As the operational time increases Monte Carlo searches have problems with creating a full coverage path. Since the number of possible paths increases factorially and the number of random paths tried is linear with time, the percentage of solution space examined rapidly approaches zero asymptotically. Practically this implies that usable full coverage paths will be found only for environments with a sweep width greater than 3% of the search area.

D. Greedy

Greedy algorithms at each time point examine the surroundings and then move in the direction that immediately covers the most area. They are usually modified for the case when the no immediate move will newly cover any area. This is accomplished by searching for a the shortest series of

moves that will get the searcher covering new area again. Greedy algorithms will readily produce solutions to both the time limited and full coverage cases, when modified as above to overcome the painting into corners problem. However they do not guarantee returning a maximal solution. A further modification to avoid the paths running predominately on diagonals in a gridded environment by dividing the potential coverage of a move by the distance to the move and then searching for the maximum move can be implemented.

A drawback of greedy algorithms is that the paths calculated tend to be incompatible with towed MCM devices. Towed devices generally require that the platform turn at a slower speed and also generally do not effectively work during the time it takes to turn and then recenter behind the platform. The advantages of greedy algorithms are speed and relatively high accuracy. For example, figure 2 compares with the benchmarks produced in [8] to those produced by the greedy algorithm. The paths are similar but the GRASP version requires 15 hours to reach this level of accuracy, yet the greedy method produces an equivalent path in less than five minutes.

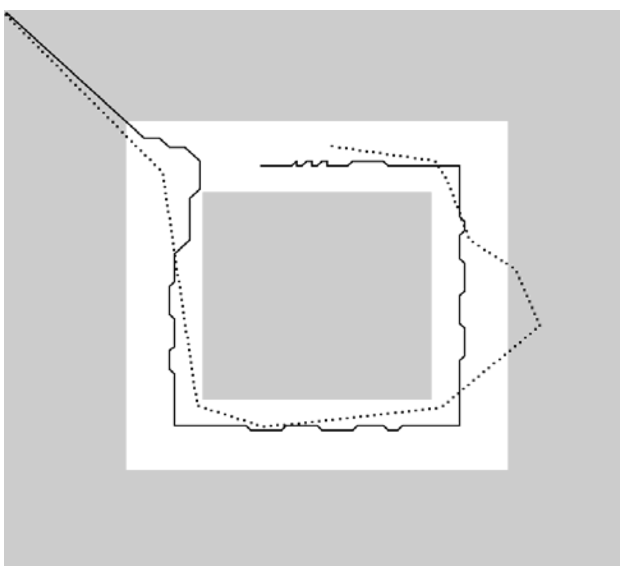

Figure 5. GRASP path is dotted and Greedy path is solid. White area are those of higher visibility.

The greedy algorithm can be extended by looking ahead several moves instead of just one. This leads to better paths but at higher computational cost. A direct analogy would be most chess playing programs. They produce better results with the more moves ahead they can examine, but take a lot of computational power to look at just one more move. In the case of mine hunting look ahead greedy algorithms hold potential.

IV. MODIFICATION TO GREEDY ALGORITHM

Greedy algorithms are modified to include a kick out. That is a threshold value for local discovery. If the searcher gets to a point where all the local moves offer too little additional coverage then the searcher determines which of the high visibility points is nearest and heads directly toward it and then resumes the greedy search.

Figure 6 points out that determining these values for both the high visibility threshold and the kickout threshold are not straightforward. The greedy algorithm has stopped short of the second ridge because there is a local hot spot short of the ridge that attracts the high visibility search. It then will go into greedy routine which will not rise onto the ridge. Figure 7 shows that with different thresholds the searcher now finds the second ridge. These graphs point to two unsatisfactory tweaking variables. These can be eliminated by instead running an array of threshold values separately and then choosing the resulting search path with the maximal coverage.

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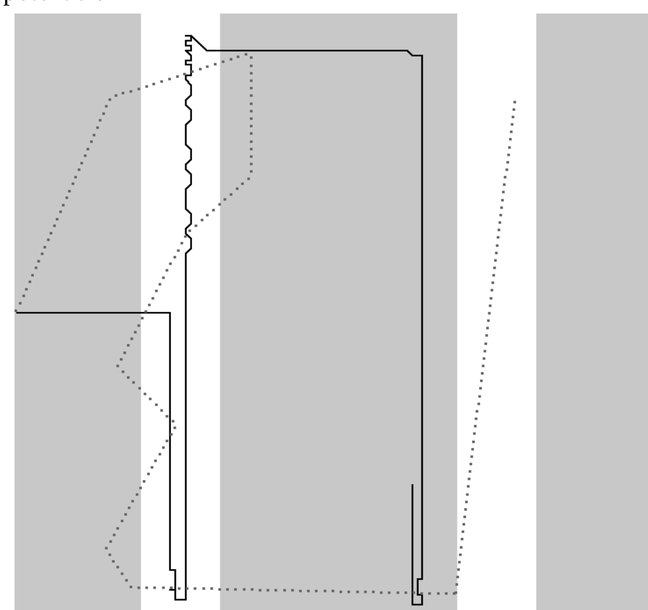

Figure 6. Comparison of Greedy, solid line, and GRASP, dotted line, for the double ridge case. White areas are the ridge crests. Gray lower elevation areas.

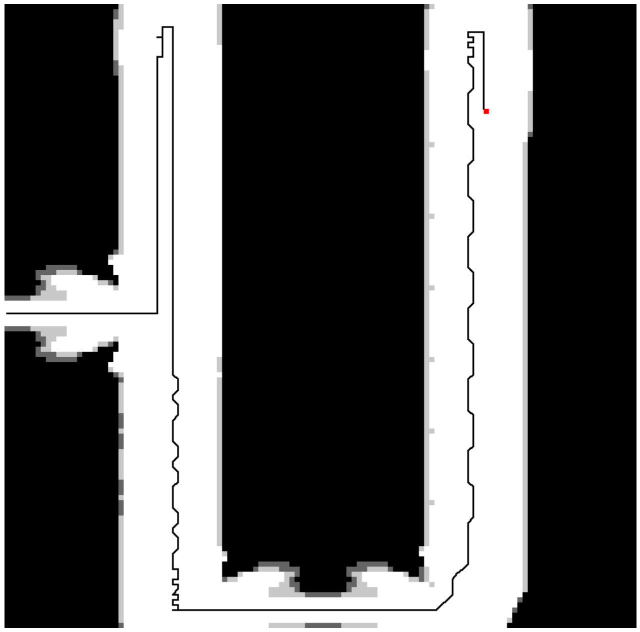

Figure 7. Greedy in same environment with different thresholds. White areas 95% covered by the path.

V. CONCLUSIONS

While present oceanographic databases do have the ability to improve mine search performance through generating search swaths for modified ladder searches, they rarely have the level of detail needed for more general path searches. However there are certain oceanographically well known areas that are sufficiently discretized and operationally as more real time data is collected more areas will be sufficiently known to need higher order search algorithms. An interesting possibility to be examined in future work is whether the platform can provide enough environmental data through self discovery to make search path calculation interesting. Further work is anticipated for blending Greedy and Monte Carlo algorithms together in an method that would share their respective strengths.

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